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(54) A HIGH INTENSITY RADIATION SOURCE

(71) We, CANADIAN PATENTS AND DEVELOPMENT LIMITED, a Company duly incorporated under the laws of the Parliament of Canada to which the Government Companies Operation Act applies and having its head Office in the City of Ottawa, Province of Ontario, Canada, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to high intensity electric arc radiation sources and in particular to radiation sources having long stabilized arcs.

Conventional stabilized arc high intensity radiation sources include a pressure vessel, a portion of which is transparent, and anode and cathode electrodes positioned coaxially within the vessel. An inert gas, such as argon, is passed through the vessel at about 4 atm and is given a tangential velocity so that it forms a vortex which constricts and stabilizes the arc between the cathode and anode. An outer transparent jacket is usually provided such that transparent cooling liquid may be circulated between the outer surface of the vessel and the outer jacket to overcome the intense heat generated by the arc. An alternative method of cooling is described in U.S. Patent No: 3,366,815 which was issued on Jan. 30, 1968 to J. E. Anderson assignor to Union Carbide Corp. In this method a small amount of liquid is bled into the arc chamber and is spread uniformly over the inner wall surface, by the vortexing gas to form a thin film. The device utilizes such a liquid film solely for the purpose of cooling the solid outer jacket and of absorbing unwanted radiation. In this and other conventional devices large gas flows are necessary to confine as well as stabilize the arc column, and also require an arc chamber with a relatively large diameter. Thus one of the major expenses in the lamp will be the gas recirculation system or the gas itself if it is not recirculated. In addition, the arc discharges in these devices have a negative dynamic impedance and therefore require current controlled power sources.

The present invention provides apparatus for providing high intensity radiation comprising:

— an elongated cylindrical arc chamber having a transparent portion;

— first and second spaced electrode means positioned coaxially within said chamber between which an arc discharge may be established;

— means for producing a cylindrical liquid wall within said chamber to constrict said arc discharge by injecting a liquid having a vortex motion into said chamber; and

— means for injecting an inert gas into said chamber to stabilize said arc discharge.

The gas injecting means may include means for vortexing said gas through the interior of said cylindrical liquid wall: in this case, the second electrode means may include an expanding chamber mounted about said second electrode for expanding said liquid vortex and said gas vortex to allow the arc discharge to expand at said second electrode surface. Alternatively, at least one of said electrode means may include an annular constriction means coaxially mounted adjacent to the surface of said one electrode means to provide a gas expansion chamber between said surface and said annular constriction means.

Arc establishing means may be provided for establishing an arc discharge between the electrode means. Preferably, the arc establishing means comprises;

— pulsing circuit means adapted to initiate said arc discharge;

— capacitor bank means adapted to sustain said arc for a predetermined time; and

— main power supply means adapted to maintain said arc.

By way of example only, apparatus constructed in accordance with the present

invention will be described with reference to the accompanying drawings, in which:

Figure 1 illustrates schematically by way of example, an arrangement embodying apparatus in accordance with this invention.

Figure 2 illustrates in cross-section, one form of apparatus in accordance with this invention,

Figure 3 illustrates a suitable starting and power circuit for apparatus in accordance with this invention,

Figure 4 (a) and 4(b) are plots of the voltages and currents provided by the starting and power circuit in figure 3,

Figures 5 and 6 illustrate two types of capacitor banks for the starting and power circuit in figure 3,

Figure 7 illustrates, in cross-section, another form of apparatus in accordance with this invention.

The dynamic impedance of an arc is defined as the ratio of the incremental change in arc voltage to the causative incremental change in current. In all arcs using vortexing gas to both stabilize and constrict the arc, a negative dynamic impedance is observed. This can be seen if the effect on the arc of a small current increase is considered. The higher current causes a higher current density which heats the arc column. The higher temperature arc not only has a lower resistivity but due to increased heating of the arc periphery the diameter of the arc becomes larger. This larger diameter and lower resistivity combine to lower the overall impedance of the discharge such that the voltage drop between the electrodes actually decreases with increased current. This situation continues until the arc diameter is restrained from increasing. In order to obtain an arc having positive dynamic impedance, it is therefore necessary to constrict the arc diameter.

The principle of operation of apparatus for providing high intensity radiation in accordance with this invention is illustrated schematically in figure 1. The apparatus 1 includes a single cylindrical arc chamber 2 with spaced electrodes 3, 4 mounted coaxially at each end. Chamber 2 is made of material, such as quartz or pyrex, which is transparent to the radiation of the arc. A high current power supply 5 is connected across the electrodes of the apparatus. A liquid pump and heat exchanger 6 flows liquid into one end of the arc chamber 2 of the apparatus so as to produce a vortexing liquid cylindrical wall 7 inside the arc chamber 2. A further pump may also circulate coolant through the electrodes 3 and 4 of the apparatus to maintain their temperature at a reasonably low level. A gas pump 8 circulates in inert gas 9 such as argon through the arc chamber 2 of the apparatus at a pressure above atmospheric, preferably between 2 and 50 atmospheres. The gas may be passed through chamber 2 in either direction. The vortexing liquid will transfer a vortexing motion to the gas entering the chamber, though means may further be provided to initially vortex the gas concentrically with the liquid as the gas enters.

The vortexing liquid cylindrical wall 7 cools the periphery of the gas column through which the arc is discharged. This cooling effect constricts the arc diameter. An increase in arc current will heat the arc, but since the liquid wall cools the arc periphery, a steeper temperature gradient occurs at the arc periphery and the arc is unable to expand. This fixed diameter gives the arc a positive dynamic impedance of approximately .005 to 0.1 ohms/cm. In addition, since the gas is not used to constrict the arc, but only to stabilize it, a low gas flow may be utilized.

For high power operation, the inside diameter of the liquid cylindrical wall 7 must be small to constrict the arc and must have a sufficient tangential velocity to maintain a uniform liquid wall throughout the chamber 2 without being appreciably perturbed by the gas column. The gas, on the other had, requires only sufficient flow to stabilize the arc.

The arrangement illustrated in Fig. 1 provides many advantages:

1) The radiation source has a positive dynamic impedance and therefore the power supply and regulation equipment is much reduced in weight and cost.

2) The far U.V. and I.R. are absorbed by the relatively thick liquid wall 7 thus lowering the amount of radiation which will be absorbed by the chamber wall 2.

3) The inside surface of the arc chamber 2 will absorb energy but since this surface is in intimate contact with the high flow liquid wall 7 the heat removal is very efficient. In double jacketed lamps the inside surface of the inside tube is heated while the outer surface is cooled. This sets up thermal stresses and allows the inner surface to become much hotter. These conditions then cause failure of the inner tube and thus lamp failure.

4) The friction encountered by the gas vortex is lowered thus maintaining a better vortex over a longer arc. This occurs because the liquid 7 and gas 9 are rotating in the same sense and the friction is due to a liquid-gas interface rather than a solid-gas. The massive liquid vortex tends to affect the gas vortex rather than be affected by it.

5) Due to the thickness of the liquid wall 7 and its velocity any material evaporated from the electrodes 3, 4 is carried away by the liquid wall 7 and thus no darkening of the solid chamber walls will occur. This will

keep radiation output constant with respect to running time.

6) Because of the rapid motion of the liquid 7 through the chamber, the liquid does not experience a large increase in temperature and therefore its cooling effect on the arc column is essentially constant over the entire length of the discharge. This produces uniform arc conditions resulting in spatial uniformity of emittance from the source.

7) Because of its thickness and rapid motion, the liquid wall 7 can sustain high power fluxes. The chamber 2 may thus have a small diameter and this in turn reduces the volume filled by vortexing gas and the volume of gas circulated may be reduced by as much as a factor 20. The smaller chamber 2 will also allow fabrication of a lamp with smaller overall dimensions whereby more economical production of highly efficient reflectors may be realized. As an example, the chamber 2 diameter need not exceed 1in for chambers up to 6ft long. However, chambers would normally be 4ins to 12ins long depending on power and use with diameters of 3/4in to 1in. The inside diameter of the liquid wall 7 within the chamber would be approximately 1/2in to 3/4in and the diameter of the arc column approximately 3/16in to 3/8in depending on the power required.

Figure 2 shows a cross-section of one configuration which the arc chamber and electrodes may take in accordance with this invention. This embodiment consists of a cylindrical arc chamber 22 made of quartz, pyrex or other material with sufficient strength to withstand the internal pressures and temperatures, and which is transparent to the arc radiation. A cathode structure 23 is mounted at one end of chamber 22 and an anode structure 24 is mounted at the other end of chamber 22 to provide spaced coaxial electrodes between which an arc is maintained.

The cathode structure 23 has a hollow electrode 25 usually made of conductive material such as copper with the cathode surface 26 made of thoriated-tungsten. Coolant is circulated through the interior of electrode 25 in any conventional manner as shown by inlet arrow 27 and outlet arrow 28. The inert gas, which may be either argon, krypton, xenon, etc. may be injected into the arc chamber 22 from either end of the chamber, however it is preferred to introduce the gas through the cathode structure 23. Though the gas would develop a vortex motion due to the vortexing liquid wall in the chamber, it is preferred to initially provide it with a tangential velocity. This is accomplished in the cathode structure 23 by providing an annulas gas chamber 29 which is concentric with electrode 25 and into which the gas in introduced by inlet 30. The gas under pressure is then forced through one or more gas jets 31 acquiring a high tangential velocity. Sleeve 32 guides the vortexing gas into chamber 22 where it travels to the anode structure 24. Finally, the cathode structure includes an annular exhaust chamber 33 into which the vortexing liquid flows as it leaves arc chamber 22. The small residual vortex motion of the liquid assists it to exit via outlet 34 and return to a heat exchanger, deionizer and pump (not shown). Most of the cathode structure may be made of conductive material such as copper except for the cathode surface 26. The anode structure 24 includes a hollow electrode 35 which has a cone shaped anode surface 36 and is made of conductive material such as copper. Electrode 35 also has an anode plug 49, usually made of thoriated tungsten, at the center of the anode surface 36. Coolant is circulated through the interior of electrode 35 in any conventional manner as shown by inlet arrows 37 and outlet arrows 38. The anode structure further includes an annular chamber 39 into which coolant is introduced under pressure through inlet 40. The coolant forms a vortex which is fast enough to take the form of a hollow cylinder 42 lining the inside of the chamber 22 before it exits into cathode structure 23. The liquid used in such a system would normally be water, however other liquids having a low vapour pressure and/or a wider range of operating temperatures, could be used. Finally, the anode structure includes an annular gas exhaust chamber 43 to receive the gas as it leaves arc chamber 22. The gas is expelled through an outlet 44 to be recirculated directly or through a heat exchanger (not shown), to inlet 30 in the cathode structure 23.

As the coolant and gas are vortexing through the chamber 22, a dc or ac arc is struck and maintained between the cathode 25 and the anode 35. The arc is constricted by the liquid wall and stabilized by the gas vortex, producing high intensity radiation which is visible through the liquid vortex 42 and the transparent chamber 22.

In order to increase the life of the anode surface 36, an annular arc constriction 45 is mounted in front of the anode 35 to form a gas expansion chamber 46 between it and the anode surface 36. The constriction 45 determines the diameter of the arc column at the end of the arc chamber 22; and the chamber 46 formed, causes the gas to expand as it enters, losing its vortex motion resulting in a non-vortex-stabilized arc at the anode surface 36. The constriction 45 which is also made of copper having a thoriated-tungsten interior surface 47, is preferably electrically insulated from the anode 35 but need not be insulated if the interior surface

47 is short enough in length. This anode structure provides a long life at high power since the thermal load is distributed over a larger surface allowing for more efficient cooling. Although the annular constriction 45 takes direct radiation and some heat from the gas, it does not carry the anode current spot. The anode surface 36 carries the current loading but the effects are reduced because there is no vortex stabilization at this surface. This lack of vortex stabilization allows a larger anode spot to form and also to rotate in an annular path, and thus the current density is reduced which lowers the thermal loading.

In addition, an iron plug 48 may be used behind the anode plug 49 to facilitate the introduction of a magnetic field which has the effect of applying a magnetic pressure to the arc in such a way that the arc is kept moving in an annular path on the anode surface in a conventional manner. Since the arc foot is moving, the thermal loading of any one part of the anode is reduced. This gives a much improved electrode life.

The cathode 25 usually projects into chamber 22 as shown in figure 2. However, a structure, similar to constriction 45, may be placed in front of cathode 25 such that the arc will cover a greater part of its surface, as would be desired for ac arc operation. The latter arrangement could also be used for dc arc operation.

Apparatus as described above is found to have a luminous efficacy higher than 40 lumens per watt at 140 kilowatts. In addition, by varying the arc parameters peak outputs may be produced in the visible or at other wavelengths.

A long high pressure arc is usually struck by momentarily touching the electrodes in a gas vortex. This has the disadvantages of perturbing the gas vortex stabilization and often causing significant electrode damage. Moveable electrode systems also prove to be inconvenient if not impossible at the top of a 200pt. lighting tower.

With the present apparatus a three stage arc starting and supply circuit of the type shown in figure 3 may be used for dc arc operation, the circuit providing a voltage and current across the arc discharge as shown in figures 4(*a*) and 4 (*b*). Initial breakdown of the arc gap 51 is accomplished by a high voltage pulse, 30,000 to 50,000 volts, lasting approximately 0.5μ sec, which is produced by a pulsing circuit 52. Since this pulse duration is not long enough for the main power supply 53 which inherently has a large inductance to take over and maintain the arc, the pulsing circuit is adapted to discharge a low inductance programmed capacitor bank 54 across the arc 41 through switch 55. The capacitor bank 54 maintains sufficient current in the arc to sustain the arc until the main supply can take over as shown in figure 4a. Diode 56 is used to block reverse current flow from the capacitor bank 54 into the main supply 53 and thus must withstand a reverse voltage equal to the maximum voltage on the capacitor bank 54. In addition, it must be capable of carrying an arc current of up to 100 amperes. When the arc is running on the main power supply, a switch 57 is closed and switch 55 is opened so that the main current can now be increased to full power since it bypasses the diode 56 and the pulsing circuit 52, preventing any damage to these components.

The programmed capacitor bank may take many forms, however it is necessary that it have a low inductance and be capable of sustaining the arc for periods of from 1 msec to 100 msec with an initial current of from 20 to 200 amps depending on the size of the radiation source. Figures 5 and 6 illustrate the type of capacitor banks which may be used in the starting and power supply circuit. In figure 5, the bank 60 includes a high voltage supply 61 feeding series resistors 62 and 63, and charging parallel capacitor 64. In figure 6, the high voltage supply 61 is again connected to resistors 62 and 63 between which a number of series inductors 64, 65, 66 are connected. A charge is then maintained on parallel capacitors 67, 68, 69 and 70, until they are discharged across the arc via the pulsing circuit as described with reference to figure 3.

Figure 7 shows a cross-section of a second configuration which the arc chamber and electrodes may take in accordance with this invention. It includes a cylindrical arc chamber 71, a cathode structure 72 mounted at one end of chamber 71 and an anode structure 73 mounted at the other end of chamber 71 to provide spaced coaxial electrodes between which an arc discharge is maintained.

The cathode structure 72 has a hollow copper electrode 74 with a cathode surface 75 made of thoriated tungsten. Coolant is circulated through the interior of electrode 74 in any conventional manner as shown by inlet arrow 76 and outlet arrows 77. Inert gas, such as argon is introduced into the cathode structure 72 through inlet 78 and forced through one or more inlet jets 79 to provide it with a tangential velocity. The cathode structure further includes an annular chamber 80 into which liquid is introduced under pressure through inlet 81. The liquid passes through tangential jets 82 to form a vortex which is fast enough to take the form of a hollow cylinder shaped wall within the chamber 71.

The anode structure includes a hollow copper electrode 83 with an anode surface 84 made of pure tungsten or tungsten alloys such as thoriated tungsten. Coolant is circu-

lated through the interior of electrode 83 in any conventional manner as shown by inlet arrow 85 and outlet arrows 86. The anode structure 73 further includes an expanding chamber 87 mounted about the electrode 83 at the end of chamber 71. The expanding chamber 87 allows the liquid vortex and gas vortex to expand before the anode surface 84 enabling the arc to expand before it reaches the anode. An outlet 88 allows the gas to exit the anode structure 73. The liquid accumulates in a liquid dump chamber 89 having an outlet 90 from which it is pumped through a suitable heat exchanger and subsequently recirculated.

WHAT WE CLAIM IS:—

1. Apparatus for providing high intensity radiation comprising:
— an elongated cylindrical arc chamber having a transparent portion;
— first and second spaced electrode means positioned coaxially within said chamber between which an arc discharge may be established;
— means for producing a cylindrical liquid wall within said chamber to constrict said arc discharge by injecting a liquid having a vortex motion into said chamber; and
— means for injecting an inert gas into said chamber to stabilize said arc discharge.

2. An apparatus as claimed in claim 1, wherein said means for producing a cylindrical liquid wall includes:
— means positioned near said first electrode means to provide the vortex motion to the liquid entering said chamber; and
— means positioned near said second electrode means to receive the liquid leaving said chamber.

3. An apparatus as claimed in claim 1 or claim 2, wherein said gas injecting means includes:
— means for circulating said gas through the interior of said cylindrical liquid wall.

4. An apparatus as claimed in any one of the preceding claims, wherein said gas injecting means includes means for vortexing said gas through the interior of said cylindrical liquid wall.

5. An apparatus as claimed in any one of the preceding claims, wherein said gas injecting means includes:
— jet means positioned near one of said electrode means to provide a vortex motion to said gas entering said chamber; and
— means positioned near the other of said electrode means to receive the gas leaving said chamber.

6. An apparatus as claimed in claim 4 or claim 5, when appendant to claim 2, wherein said liquid and said gas are vortexed concentrically.

7. An apparatus as claimed in any one of the preceding claims, wherein said gas is at a pressure at or above atmospheric pressure within said chamber.

8. An apparatus as claimed in any one of the preceding claims, wherein the distance between the electrodes means is greater than five times the diameter of the arc column.

9. An apparatus as claimed in any one of the preceding claims, wherein the chamber has an inside diameter between 1/4 inch to 1 inch.

10. An apparatus as claimed in any one of the preceding claims, wherein the liquid is water.

11. An apparatus as claimed in any one of the preceding claims, wherein at least one of said electrode means includes an annular constriction means coaxially mounted adjacent to the surface of said one electrode means to provide a gas expansion chamber between said surface and said annular constriction means.

12. An apparatus as claimed in claim 4 or claim 5, when appendant to claim 2, wherein said second electrode means includes an expanding chamber mounted about said second electrode for expanding said liquid vortex and said gas vortex to allow the arc discharge to expand at said second electrode surface.

13. An apparatus as claimed in claim 1, including means for establishing an arc discharge between the electrode means, and wherein said arc establishing means comprises;
— pulsing circuit means adapted to initiate said arc discharge;
— capacitor bank means adapted to sustain said arc for a predetermined time; and
— main power supply means adapted to maintain said arc.

14. Apparatus for providing high intensity radiation, substantially as described herein with reference to, and as illustrated by, Figs. 1 and 2 of the accompanying drawings.

15. Apparatus for providing high intensity radiation, substantially as described herein with reference to, and as illustrated by, Figs. 1 and 7 of the accompanying drawings.

16. Apparatus according to claim 1, including arc establishing means substantially as described herein with reference to, and as illustrated by, Figs. 3 to 6 of the accompanying drawings.

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1468137 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

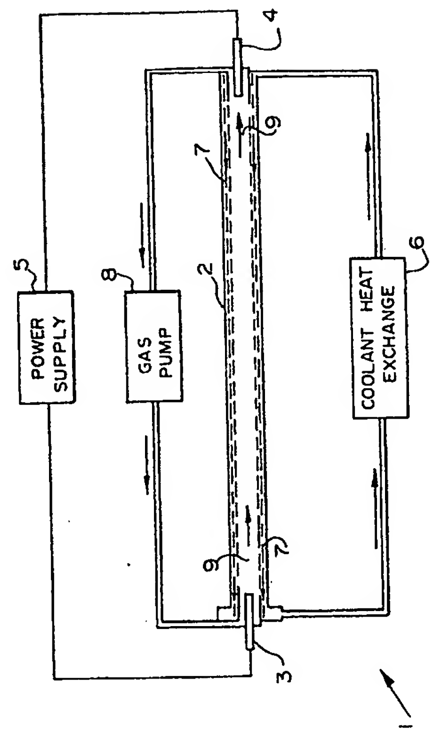

FIG. 1

1468137 COMPLETE SPECIFICATION

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Sheet 2

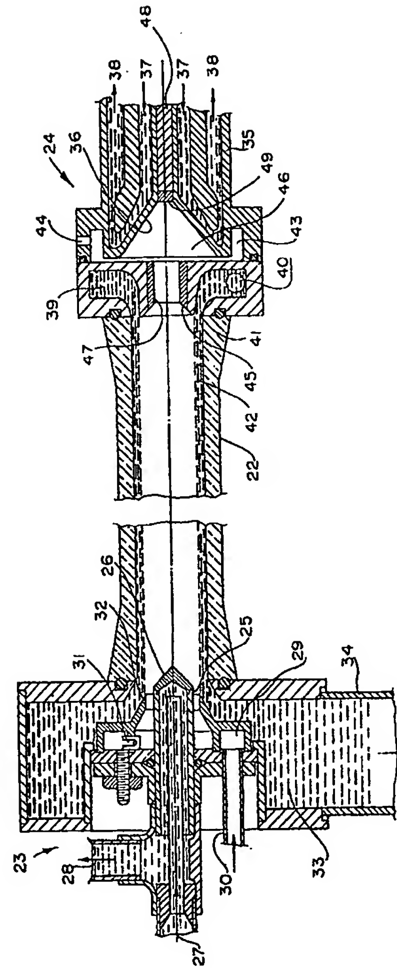

FIG. 2

1468137 COMPLETE SPECIFICATION

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Sheet 3

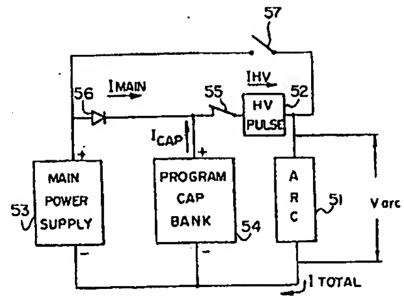


FIG. 3

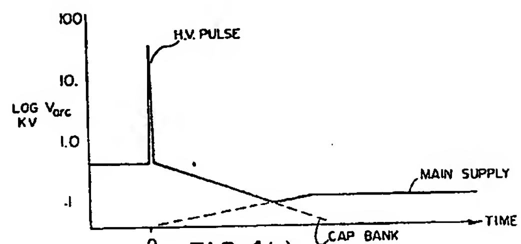


FIG. 4(a)

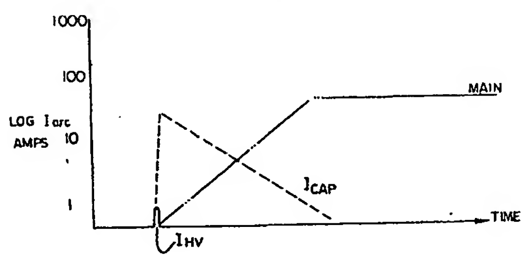


FIG. 4(b)

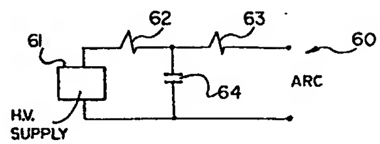
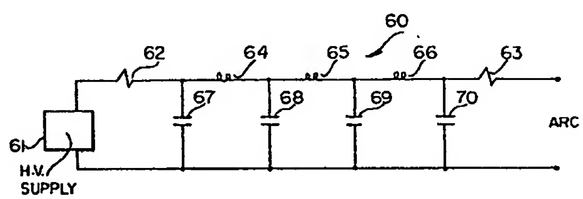

61
62
63
60
64
ARC
H.V.
SUPPLY

FIG. 5


60
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70
ARC
61
H.V.
SUPPLY

FIG. 6

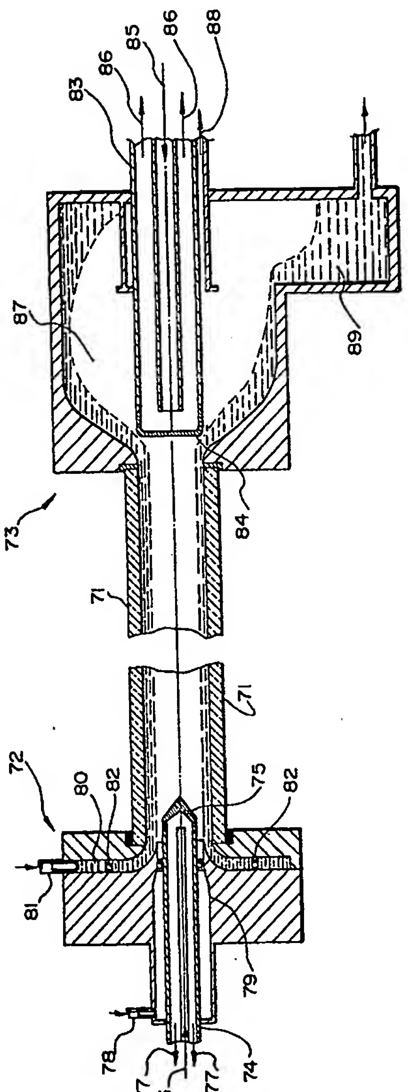

FIG. 7